Statistical Characterization and Classification of Fish School Clutter

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LONG-TERM GOALS

To significantly reduce the probability of false alarm in Navy active sonar systems. This goal will be achieved through developing signal processing algorithms for active sonar systems which can account for the non-Rayleigh nature of clutter from fish schools. Part of this goal will involve characterizing the performance of the algorithm.

OBJECTIVES

To investigate the statistical properties of echoes recorded from a unique broadband active mid-frequency acoustic system which we are using to study schools of fish and to incorporate the results into existing classifiers.

APPROACH

This study takes advantage of broadband acoustic data collected in another program (N00014-1-04-0440). The active sonar was towed over schools of fish and echoes were recorded from 1000's of transmissions. The system transmitted chirps over the frequency range 2-14 kHz, with most of the energy in the 2-4 kHz range. This range also coincided with the resonance frequency of the swimbladder of the fish, giving rise to strong echoes. The echoes were observed to be strongly non-Rayleigh. The objectives will be accomplished by extending our approach from the original pilot project (preceding this grant) of determining various conditions under which the echoes are non-Rayleigh, further development of the candidate PDF's identified in that pilot study, and incorporating physics-based features of the PDF's into standard discriminators. A preliminary study of the statistics of fish patches will also be conducted for possible future use in predicting echo statistics of random patches.

WORK COMPLETED

The research has spanned several directions, all related to measuring and modeling echo statistics associated with patches of fish:

1) As summarized above, in another grant (ONR Ocean Biology), we have collected echo data using a mid-frequency active sonar involving aggregations of Atlantic herring over Georges Bank 100 east of Cape Cod. In this current grant (Undersea Signal Processing), we have grouped the echoes in various data windows so that the echo statistics could be studied for a variety of conditions (Figs. 1, 2):

a. resolved fish
b. sonar beam within a patch
c. sonar beam sweeping across a single patch edge
d. sonar beam sweeping across multiple patches.

2) Investigated several candidate theoretical PDF's to model the echo statistics in the above four categories. The standard Rayleigh, mixed Rayleigh, and K-distribution PDF's were investigated, as well as one previously published by others which incorporates the sonar beampattern and echo PDF of the target (without beampattern effects) explicitly for the case of resolved fish. As part of the investigation we:

a. extended the interpretation of the K-distribution through rederiving it and making more explicit the connection between its parameters and the scattering phenomena.

b. extended the use of the beampattern-specific PDF through generalizing it.

3) Compared above theoretical PDF's to our mid-frequency echo data involving patches of fish for the various types of data windows (Figs. 3 - 5). The comparisons demonstrated excellent agreement with the beampattern-specific PDF (resolved echoes) and mixed Rayleigh PDF (sonar beam spanning single edge of patch and multiple patches). Also, the K-distribution PDF showed reasonable agreement with patch data, especially for the case of spanning multiple patches.

4) Developed a new general theoretical PDF for describing a finite number of arbitrary patches, each randomly distributed in a directional sonar beam, and each with their own echo PDF. The new formulation is general and not specific to fish. Comparisons between simulations and the theory were excellent (Fig. 6).

5) Investigated candidate models of fish patchiness for eventual use in echo statistics predictions. After a search of the literature, the candidate model is a truncated power law. We have investigated the statistics of the cross-sectional area (as measured via echograms) of our fish patch data and have determined that this area is power-law distributed.

6) Publications. We have published three IEEE Oceans proceedings describing various stages of the above work (Stanton et al., 2006; Chu and Stanton, 2007; and Chu and Stanton, 2008). In addition, we have submitted three manuscripts intended for the (refereed) special issue on clutter

in the IEEE Journal of Oceanic Engineering (guest editors, Doug Abraham and Tony Lyons). At the time of this writing one has been conditionally accepted.

The papers are summarized:

Non-Rayleigh echoes from resolved individuals and patches of resonant fish at 2-4 kHz (T.K. Stanton and D. Chu). This work involves analyzing the echo data collected with a mid-frequency sonar on another ONR grant (Biology) for various groupings of echo data (involving resolved individual fish, and patches of fish as described above-- all data from within a patch, spanning across a single patch edge, and spanning across multiple patches). Conditions under which the data are strongly non-Rayleigh are identified, comparisons are made between theoretical PDF's and data, and the data sets are discriminated through calculating distances between various theoretical PDF's and data (as described above). A key element of this work is connecting parameters of the PDF to physical quantities associated with the data.

Further physical interpretation of the K-distribution (D. Chu and T.K. Stanton). This work builds on the previous work of Abrahams and Lyons where they related parameters of the K-distribution to an exponentially distributed group of scatterers. In this new work, we begin with a fundamental scattering formulation and put it into a form for use in the derivation of the K-distribution. Through this exercise, the connections between the K-distribution parameters and the scatterers are more explicit.

Statistics of echoes from a directional sonar beam insonifying finite numbers of single scatterers and patches of scatterers (D. Chu and T.K. Stanton). This work connects the results of Ehrenberg, who expressed the echo distribution (as seen through the sonar receiver) in terms of the beampattern PDF and PDF of the echo of the scatterer (before beampattern effects), and the results of Barakat, who derived a general expression for the signal PDF due to the summation of a finite number of random variables. Through connecting these results (which includes extending Ehrenberg's results), we have developed a general formulation for the echo PDF (as seen through the sonar receiver) due to an arbitrary number of scatterers or patches, each with their own arbitrary echo PDF (before beampattern effects), and each randomly distributed in the sonar beam. The formula is general and is not specific to the fish problem (for example, it could be applied to patches of seafloor scatterers). The paper gives the extension to the Ehrenberg formula, summarizes the Barakat formulation, connects the two in the context of echo statistics of random scatterers in a sonar beam, and gives examples of the solutions for various combinations of important conditions.

RESULTS

As a result of the theoretical development and analysis of data, we now have a broad understanding of the problem of echo statistics in relation to patches of scatterers. Although the specific application was to fish, the theoretical development was for any type of patches. For the fish application, and as a result of analysis with mid-frequency data, we have an understanding of the conditions under which the echoes are strongly non-Rayleigh, the appropriate theoretical PDF's to use, and the class of discriminator to use (log-based for the tails). Key to all analysis is influence of the beampattern on the statistics. Finally, a candidate descriptor for patch statistics of fish has been identified for future implementation into the general echo statistics model.

IMPACT/APPLICATIONS

Our general theoretical formulation is broadly applicable to any type of patch—fish, seafloor patches, etc. Our analysis involving mid-frequency echoes from swimbladder-bearing fish shows the echoes to be strongly non-Rayleigh under important conditions. Our general formulation is therefore useful in making predictions to improve the performance of ASW active sonar systems. Key to the predictions is having a mathematical model for fish patchiness. Incorporating the candidate model for patch statistics identified in this project with our general echo statistic models would provide for a generic predictor for echo statistics from patches of fish.

RELATED PROJECTS

This research draws from the data collected in another ONR project (N00014-1-0440, Biology). In that project, a broadband active mid-frequency acoustics system has been towed over aggregations of fish to study distributions of fish. In a recent cruise, NRL (Roger Gauss and colleagues) participated through towing their broadband mid-frequency system that looked horizontally at long ranges at the fish. The focus of the project is to study the fish through resonance classification. High quality acoustic data were collected, in combination with net samples to ground truth the data, showing non-Rayleigh echoes from fish that survived a normalizer.

PUBLICATIONS

Manuscripts submitted to (refereed) IEEE Journal of Oceanic Engineering, special issue on Clutter:

Stanton, T.K. and D. Chu, "Non-Rayleigh echoes from resolved individuals and patches of resonant fish at 2-4 kHz," conditionally accepted to *IEEE J. Ocean. Eng.*

Chu, D. and T.K. Stanton, "Further physical interpretation of the K-distribution," submitted to *IEEE J. Ocean. Eng.*

Chu, D. and T.K. Stanton, "Statistics of echoes from a directional sonar beam insonifying finite numbers of single scatterers and patches of scatterers," submitted to *IEEE J. Ocean. Eng.*

Proceedings published that are an abbreviated or preliminary form of the above:

Stanton, T.K., D. Chu, J.M. Jech, and J. D. Irish. "Statistical behavior of echoes from swimbladder-bearing fish at 2-4 kHz," Proceedings of the MTS/IEEE Oceans '06 Conference, Boston, 2006.

Chu, D. and T.K. Stanton, "Non-Rayleigh echo PDF's for broadband acoustic scattering by patches of discrete targets with applications to fish," Proceedings of the IEEE Oceans 07 Conference (Aberdeen), 2007.

Chu, D. and T.K. Stanton, "Classification of non-Rayleigh echoes from patches of fish," Proceedings of the MTS/IEEE Oceans 08 Conference (Kobe), 2008.

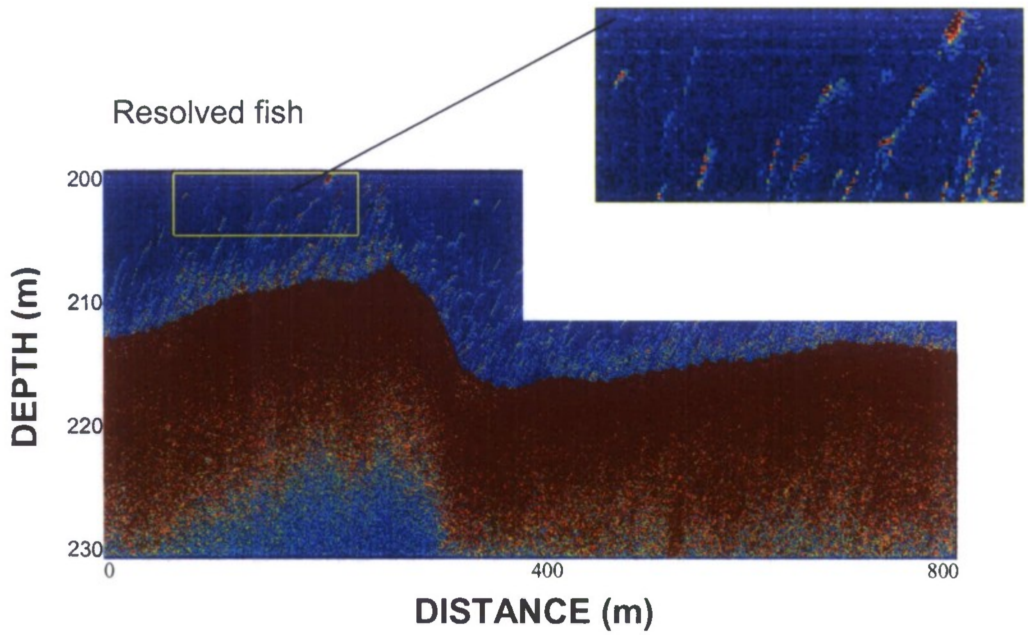

Figure 1. Echogram of resolved fish as collected in the 2-4 kHz band. The yellow box corresponds to the window in which the echo statistics were analyzed. From Stanton and Chu (conditionally accepted).

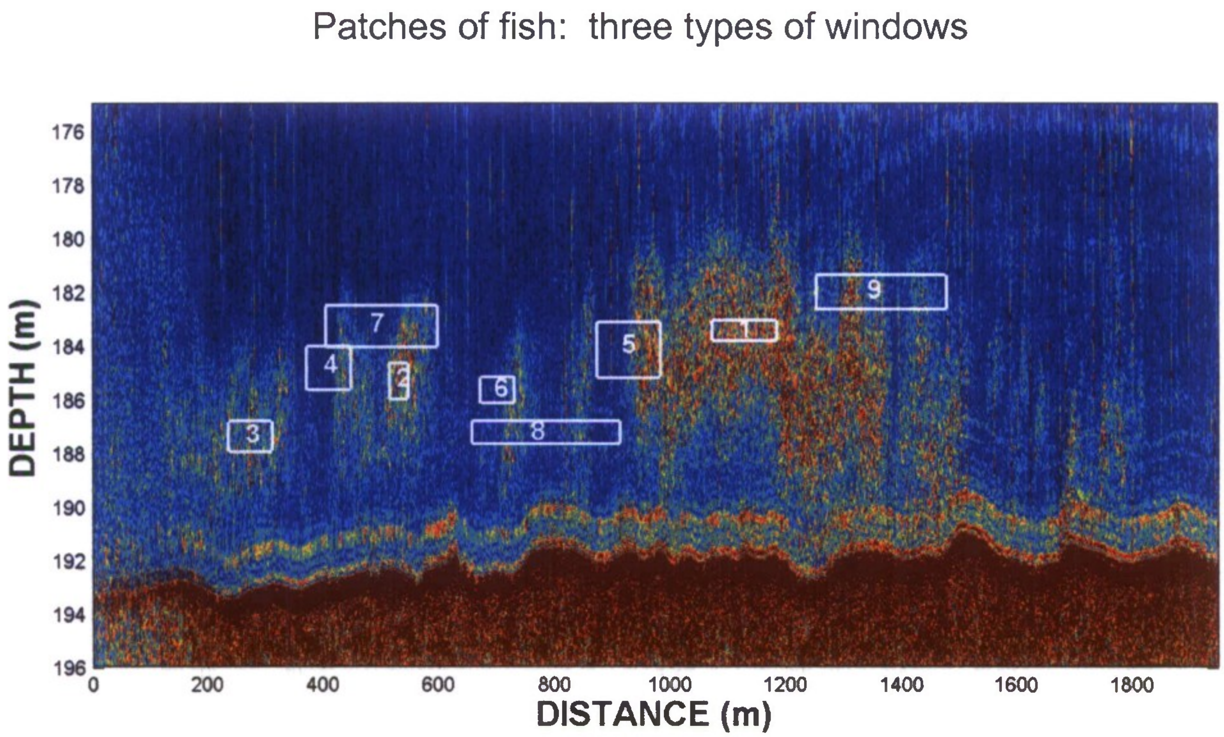

Figure 2. Echogram involving patches of unresolved fish as collected in the 2-4 kHz band. The nine white boxes correspond to the windows in which the statistics were analyzed. From Stanton and Chu (conditionally accepted).

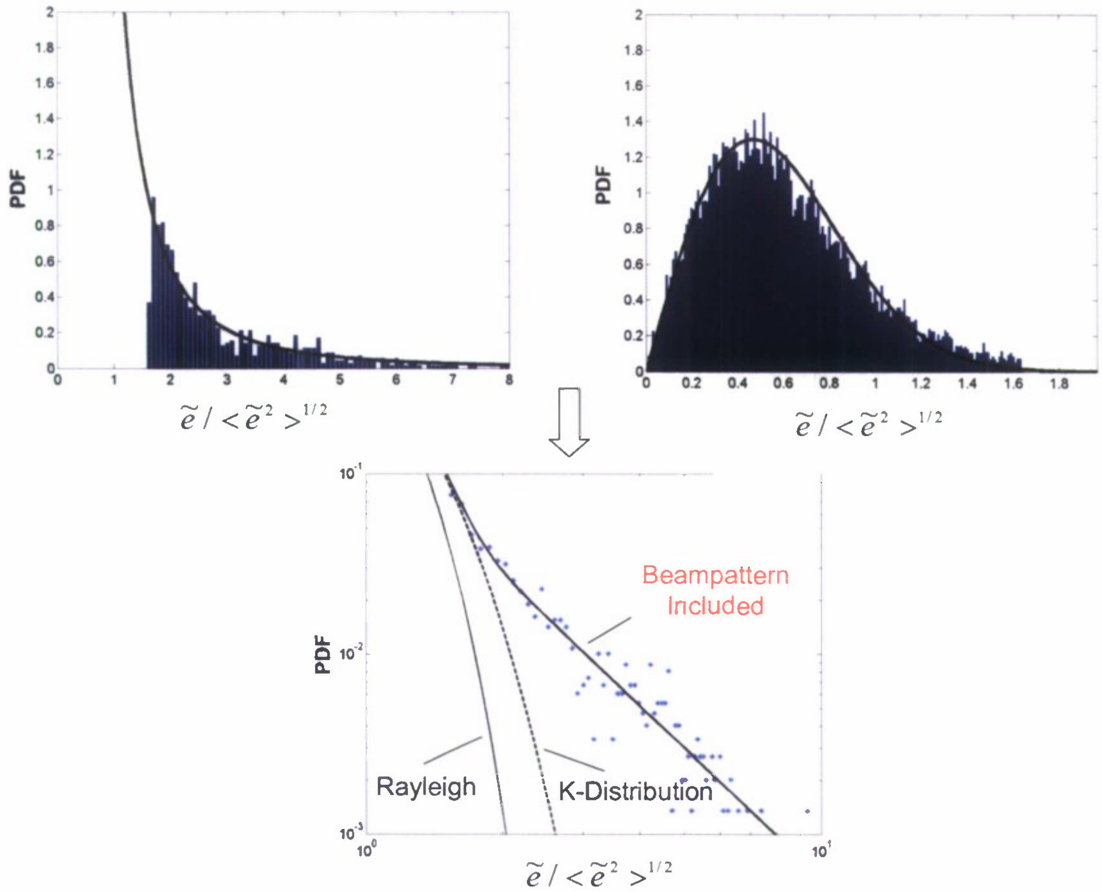

Figure 3. Echo statistics associated with resolved fish from Fig. 1. From Stanton and Chu (conditionally accepted).

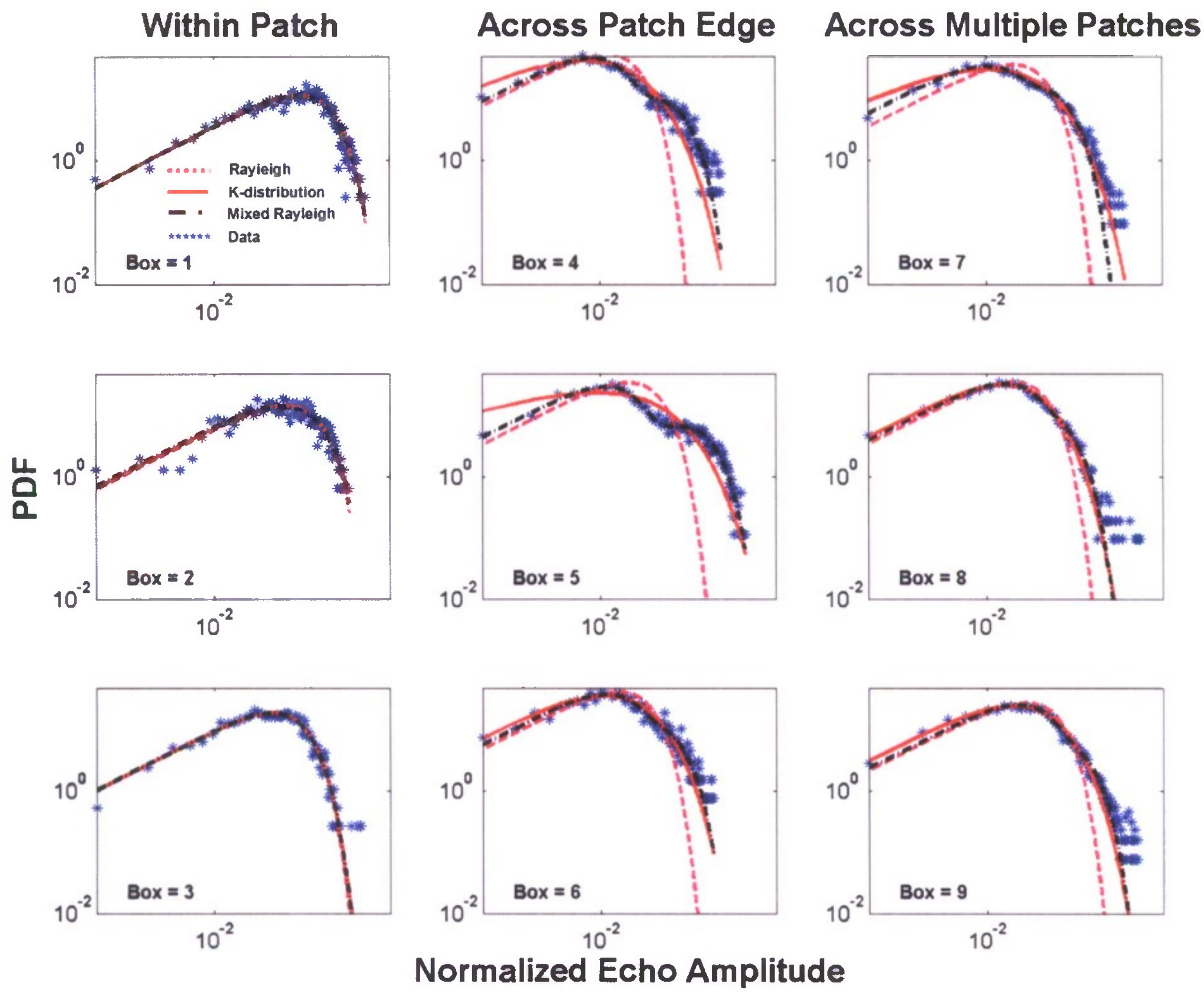

Figure 4. Echo statistics associated with patches of fish from Fig. 2. From Stanton and Chu (conditionally accepted).

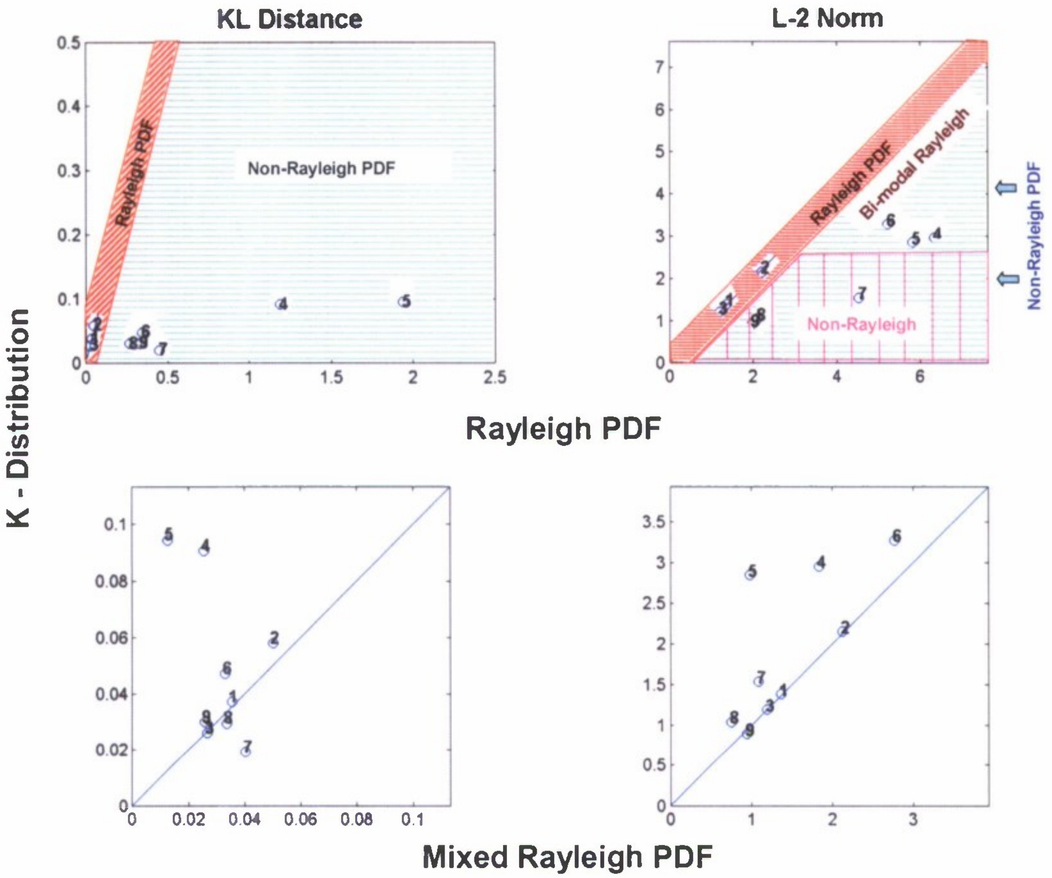

Figure 5. Distances between various theoretical PDF's and data from Fig. 4, as calculated through two methods—KL distance and L-2 norm distance. The line in each plot has a slope = 1 to delineate differences between use of the different theoretical PDF's. From Stanton and Chu (conditionally accepted).

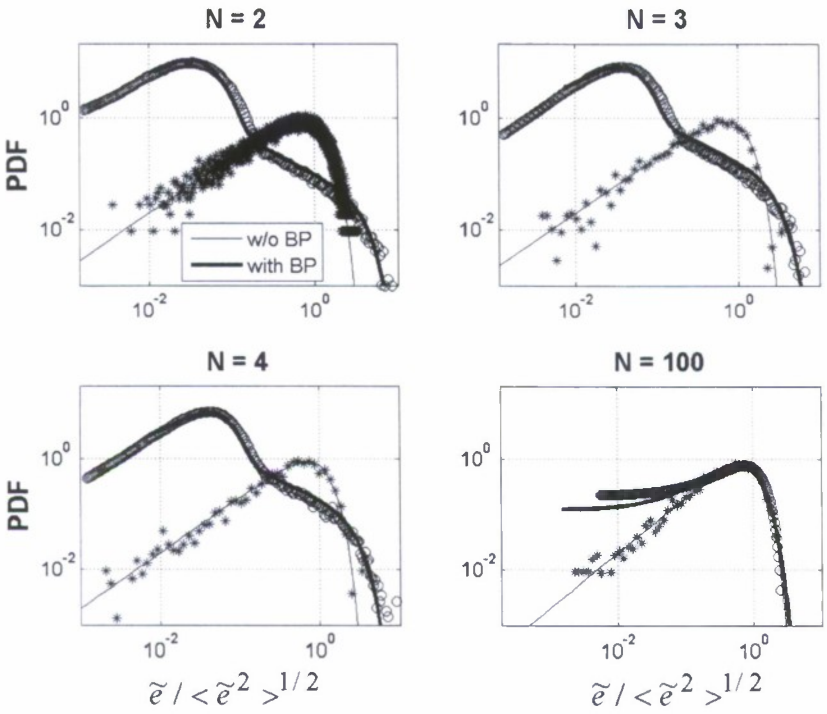

Fig. 6. Effects of beampattern for N multiple unresolved scatterers, each randomly and independently located in the beam. The echo from each scatterer before beampattern effects is Rayleigh distributed, each with the same mean. Predictions using our new formulation (thick solid line) are compared with numerical simulations ("o"). Corresponding calculations (thin line; "*") are made for the case where there are no beampattern effects (i.e., omnidirectional beam). From Chu and Stanton (submitted).

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14. ABSTRACT
To understand and exploit acoustic reverberation by and transmission through fish and related acoustic signal processing The focus will be on swimbladder-bearing fish with resonance frequencies in the 100's of Hz to low kHz.

15. SUBJECT TERMS
broadband acoustics, signal processing, and fish school clutter

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